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I am Dr. Leonard Levin, technical executive at the Electric Power Research Institute (EPRI). EPRI is an independent nonprofit research organization based in Palo Alto, California, with other major offices in Knoxville, TN and Charlotte, NC The various research groups at EPRI have been conducting investigations of environmental mercury sources, fate, human effects, and controls for more than twenty years, spending between $10 million and $20 million per year on that research.

In the last several years, much of this work has been spent on clarifying the environmental and health consequences that will ensue from regulation of U.S. utility mercury emissions, and the decline of those emissions over time. Much of this recent effort has examined what the public health benefits might be from individual states, or federal agencies, applying stricter control levels than the ones that would follow from implementation of Clean Air Interstate Rule (CAIR) and the Clean Air Mercury Rule (CAMR) promulgated by the U.S. Environmental Protection Agency. In parallel, EPRI has joined with the U.S. Department of Energy, the utility industry, and equipment vendors in development, testing, and demonstration of effective and predictable mercury controls for the coal-fueled electric utility industry. This testimony summarizes recent findings in both areas – the presence and effects of mercury in the U.S. environment, and the current status of mercury controls.

SUMMARY OF OUR CURRENT UNDERSTANDING

1. Controls of mercury more stringent than the EPA 70% national level appear to have diminishing returns, primarily due to intercontinental mercury transport from Asia and the form of mercury remaining in utility emissions after reaching the EPA target;

2. Federal data show that mercury exposure in women of child-bearing age appears to have declined over the past decade, for reasons that are unclear (particularly since these women are eating more fish);

3. State-level controls that bypass the Federal cap-and-trade system for mercury may actually lead to higher mercury deposition within that state, even for stricter control levels;

4. EPRI cannot say with confidence that 90%-effective mercury control technologies are commercially available for all affected power plants.

MERCURY IN THE U.S. ENVIRONMENT

Research on mercury in the environment continues to improve our understanding of the substance and its sources, transport, cycling, and human and ecosystem exposure and health. As instrumental and analytical methods improve, and process modeling more rapidly integrates basic scientific findings about the chemical, the ability of investigators to discern effects on the environment improves. This cascade of new information requires diligent integration into an overall understanding of mercury sources and effects, allowing investigators to bound the issue in realistic terms, neither overestimating the impacts of very low exposures nor ignoring the effects manifested in extremely subtle alterations to health and welfare.

This testimony is focused on our state of understanding of mercury, including several critical findings that were developed by EPRI and other investigators primarily during 2006 and early 2007. The investigations reported here are small parts of the work going on globally in each of the areas studied: mercury sources, human exposure, health effects, and subtle lifelong impacts that might evince themselves as study methods improve. That evolution in methodology, measurement, and assessment is integral to all research progress, but in the case of mercury and other toxicants, has a direct link to societal response to the environmental questions raised. That is because policy, particularly regulatory, consequences of what are viewed as environmental pollution problems are linked to the ability of researchers to discern, discriminate, measure, and bound the magnitude of effects from human exposure to toxicants. As the number of studies increases over time, and methods for investigating responses to environmental pollutants improve, the detection of effects will reach finer and finer levels of concentration and dose. We can expect a concomitant evolution in the methods for gauging the significance of subtle effects on human health and welfare.

Mercury As a Global Pollutant

- *Background Sources of Mercury.* As a chemical element in the earth's crust, mercury has always been ubiquitous in trace amounts in the environment, even prior to the Industrial Revolution. There is, for example, good archeological evidence that Native American peoples in the pre-European era used set wildfires for land clearing and herding of wild animals; geological samples from peat bogs and lake sediments show extended periods of elevated mercury in the atmosphere from these occurrences. As a result of this occurrence, and its association with fossil fuels, mercury has a wide suite of sources in the modern world. It is useful to categorize mercury's sources broadly into human, or anthropogenic, sources (such as fossil fuel combustion), and background sources (such as emissions from geothermal vents or from abandoned mine tailings). The category of background sources – natural emissions of native mercury, mercury re-emitted from the surface after earlier deposition, and geological mercury exposed to the atmosphere by human disturbance – has assumed increasing importance in the global and regional mass balances of the substance. Recent findings have indicated that, globally, new natural sources of mercury may be twice as large as previously thought, further reducing the significance of anthropogenic sources in the global mass flow.

- *Anthropogenic Mercury Emissions.* Table 1 shows a recent inventory [1] of global mercury emissions. The notable point is that, not only are total Asian emissions about an order of magnitude greater than those of North America, but Asian so urces are the "nearest" upwind sources in the dominant westerl y winds that blow at midlatitude in the Northern Hemisphere. In particular, emissions from China are believed to total more than half of all continental emissions from Asia, and China is most di rectly upwind from the United States. It should also be noted that country -by-country yearly inventories, when available, indicate that emissions on all populated continents except Europe and North America are increasing, while Europe and North America are decreasing, over time.

Table 1. Global anthropogenic emission inventory for total mercury (datum year 2000)

Country or continent	**Annual mercury emissions (U.S. tons per yr)**	**Reference**	**Possible uncertainty**
United States	115	EPA, 2004 (a)	+ 77 tons/yr (b)
Canada	9	EPA, 2004	
Mexico	29	CEC, 2001	Within ±1.8 multiplier (c)
Asia	1327	Pacyna, 2003	x2 (d)
Europe	263	Pacyna, 2003	
South & Central America	101	Pacyna, 2003	
Africa	449	Pacyna, 2003	
Oceania	138	Pacyna, 2003	
Total	**2432**		

(a) 1999 inventory
(b) +50 tons/yr of unaccounted Hg used in chloralkali plants (Southworth et al., 2004); +28 tons/yr of Hg emissions from motor vehicles (Edgerton et al., 2004).
(c) Uncertainty factor derived from the range in Mexican emissions estimated by Pai et al. (200 0).
(d) Estimate based on atmospheric Hg ex port estimates from Jaffe et al. (2005).

- *Trends in Mercury Emissions and Concentrations*. Mercury, as a global pollutant, exhibits significant fluctuations in concentrations due to distant sources. Inventories o f coal use in China by David Streets, of Argonne National Laboratory, and colleagues showed a year-by-year increase in coal use in China of up to 11% since the 1990s. More strikingly, there is direct evidence of this increase in emissions at distant points on the globe, such as the middle of the Atlantic Ocean, more than

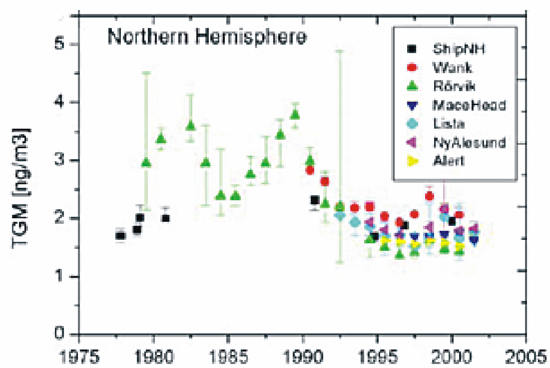

Figure 1.
From: "Worldwide trend of atmospheric mercury since 1977," F. Slemr et al., 2003; ***Geophysical Research Letters, 30,*** 10.

[1] K Lohman, C Seigneur, M Gustin, S Lindberg; 2007; **"**Sensitivity of the Global Atmospheric Cycling of Mercury to Emissions," *Environmental Geochemistry* (submitted)

half a world away. Work by Franz Slemr et al.[2] shown in Figure 1 found that global atmospheric mercury has generally been declining for 30 years, but has leveled off in the last 10 years. Inventories compiled on mercury emissions from China by Wu et al.[3] of Argonne National Laboratory have shown Chinese mercury emissions growing by up to 10% per year, and on average about 3% per year, since the 1990s . The Slemr et al. results match up with the decline in background mercury levels underway since the 1950s or 1960s, shown in data by Benoit et al.[4] and Swain and Engstrom[5]. Growth in mercury emissions on continents other than Europe and North America (where emissions are declining) may now be impacting the global balance of the substance.

Mercury Exposure and Health Effects

- *Mercury Exposure of U.S. Women.* U.S. federal measurements of the health and exposure status of a cross-section of American residents have been carried out for a number of years. These studies, NHANES (National Health and Nutrition Exposure Study), add several thousand adults and children to the database year. The survey includes data on blood sample levels of trace substances, vital statistics, recall surveys on diet, and other factors. One element of this survey is blood and hair tests of children (ages 0-6) and women of childbearing years (ages 16-49) for mercury levels. The adults are also surveyed for recall of the amounts and types of fish consumed in the month prior to the clinical tests being performed. Samples and surveys are analyzed and coded, and results are issued for biennial reporting periods. By early 2007, results for the 1999-2000, 2001-2, and 2003-4 biennia were published and available for further analysis. The NHANES data have shown a continuing, statistically significant, and so far unexplained drop in women's mercury exposure over the last 8 years (Table 2)[6]. The number of US women with blood mercury levels above the EPA health threshold (a threshold set to be protective of all individuals) has dropped from more than 7% in 2000 to below 2% in 2004. Yet the diet surveys of the tested women showed an increase in fish consumption in that same period.

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[2] F Slemr, E-G Brunke, R Ebinghaus, C Temme, J Munthe, I Wängberg, W Schroeder, A Steffen, T Berg; 2003; "Worldwide trend of atmospheric mercury since 1977," *Geophysical Research Letters, 30,* 10, 1516, Doi:10.1029/2003gl016954.

[3] Y Wu, S Wang, D G Streets, J Hao, M Chan,J Jiang, 2006; "Trends in Anthropogenic Mercury Emissions in China from 1995 to 2003," Environ. Sci. Technol., 40, 5312-5318

[4] J M Benoit, W.F. Fitzgerald, A.W.H. Damman. 1994. "Historical atmospheric mercury deposition in the mid-continental United States as recorded in an ombrotrophic peat bog. " In: C. Watras and J. Huckabee (eds.), *Mercury Pollution: Integration and Synthesis*.Lewis Publ., Boca Raton, FL, pp. 187-202.

[5] D R Engstrom, E B Swain, 1997; "Recent Declines in Atmospheric Mercury Deposition in the Upper Midwest," *Environ. Sci. Technol., 31*, 960-967

[6] C. Whipple, 2007; "Insights From Six Years of Mercury Biomarker Data," in L. Levin, *Mercury in the Environment: A Research Review*, EPRI Report 1012572; Final Report, March 2007; Electric Power Research Institute, Palo Alto.

Table 2. Federal NHANES Survey, Blood Mercury Concentration, U.S . Women Aged 16–49

Survey Biennium	Number of Subjects	Mean Total Mercury in Blood, µg/L	Percent of Women with Blood Mercury Above EPA Health Threshold
1999–2000	1709	2.00	7.1%
2001–2002	1928	1.45	3.4%
2003–2004	1824	1.35	1.9%
1999–2004	5461	1.58	3.96%

- *Mercury Effects on I.Q. Levels*. The NHANES data in turn have implications for analyses of mercury effect on neurobehavioral outcome and indirect consequences, such as the published claim linking losses in lifetime earnings to IQ decrements brought about by prenatal exposure to mercury[7 8]. The entire Trasande analyses rest on a number of assumptions that link mercury exposure in the U.S. to lifetime earnings of both exposed and unexposed individuals. The initial assumption is that an IQ decrement (excess incidence of below-normal IQs) is related to later-in-life earnings via either lower success in finding employment and staying employed, or lower success in finding high-paying employment. Griffiths et al.[9] recalculated the numbers of Trasande et al. by re-examining the range of values from which each individual value in the original analysis was selected. When Griffiths et al. selected mid-range or "best estimate" values, rather than the extreme values stated to be used by Trasande et al., the dollar cost per year of IQ decrement due to mercury from all sources declined by some 88%. More importantly, Griffiths et al. found that the portion of the annual cost attributable to U.S. power plant mercury was best estimated by a fraction 98% lower (1/50th the value) of the 0.4% attribution cited by Trasande et al. This is another example of the limits – the "floor" – on how much benefit can be gained from controlling only utility mercury.

  When the Trasande et al. analyses published to date are reassessed using more current NHANES findings, the consequences of mercury exposure for performance, labor market participation, lifetime earnings, and other consequences drop by at least an order of magnitude. A paper by Schmier et al. (2007), submitted to *Environmental Research*, also re-examined the Trasande et al. work. Part of the Trasande analysis involved use of the first biennial NHANES data, from 1999-2000. When Schmier et al. recalculated the values using the NHANES results from 2001-2002 and 2003-2004, they found that the overall costs dropped by 60%.

- *Adult Cardiovascular Effects.* Some studies in recent years have hinted at a later-in-life impact from lifetime mercury exposure that evinces itself in male cardiovascular health issues, including elevated rates of myocardial infarction and coronary heat disease. These studies, however, have tended to focus on multiple re-investigations of a single, limited subject cohort in a single region of the world. Unique dietary and lifestyle factors have not, to date, been considered or isolated in those studies, while other

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7 L Trasande, PJ Landrigan, C Schechter. 2005. Public health and economic consequences of methyl mercury toxicity to the developing brain. In: *Environ Health Perspect 11*(5):590-6.

8 LTrasande, C B Schechter, K A. Haynes, P J. Landrigan, 2006;Mental Retardation and Prenatal Methylmercury Toxicity, in: *American Journal of Industrial Medicine 49*:153–158 (2006)

9 C Griffiths, A McGartland, M Miller, 2007; A Comparison of the Monetized Impact of IQ Decrements from Mercury Emissions. In *Environ Health Perspect* doi:10.1289/ehp.9797

> investigations using different subject groups show inconsistent results for the same effects. An extensive literature review and analysis (ter Schure, 2007)[10] reports on the findings to date across the research community, weighing the net result of the technical evidence to arrive at an evaluation of the likelihood of later-in-life mercury impacts on cardiovascular health. The conclusion of this weight-of-evidence review is that studies to date do not support increases in coronary heart disease due to higher mercury exposure in children or adults. Such outcomes have been found in a single, relatively small cohort with dietary practices significantly different from those in most western countries, and in the United States in particular.

It is important to remember that the potential health effects of mercury on United States residents is almost exclusively through consumption of fish containing possible excess levels of mercury. Extensive research over several decades has found that the subjects most sensitive to this kind of mercury exposure are developing fetuses, whose nervous systems may experience subtle developmental damage from mercury binding to proteins during periods of critical organ growth. Thus, the fish consumption practices of women of childbearing age are the exposure routes of greatest concern.

From survey data throughout the country, we know that at least 90% of the foodfish in commerce is from global ocean areas. At least ¾ of that marine fraction is from northern or southern Pacific catch areas, essentially the other side of the globe from the United States in the dominant wind direction of west-to-east. For that reason, changes in U.S. mercury emissions reaching domestic freshwater U.S. fish would play a minor role in the overall change in mercury exposure to women, and their developing babies. In essence, there is a built-in "floor" bounding how much mercury exposure – the basic public health concern – can be reduced by controlling U.S. mercury sources alone.

Mercury Deposition Following Federal and Federal+State Regulation of Utilities

Federal and state steps to regulate emissions of mercury from coal-fired power plants (CFPPs) will result in consequences for the deposition of mercury within and external to the U.S. In most cases, reducing mercury emissions will result in reduced deposition, although often in complex patterns not easily related to the emissions drops themselves. This reduction in deposition is conditional, however, on the allowances made for the trading of mercury emissions credits. The U.S. EPA Clean Air Mercury Rule (CAMR) allows utilities which control mercury emissions to below their state-allocated levels to sell the additional mercury "saved" on open markets to buyers (usually other utilities). This provides an economic incentive for some utilities to lower their emissions at individual power plants to below their state allocation(s). Since 2005, however, a number of proposed state-level utility mercury emissions targets (composed of either or both amounts of mercury emitted and target date for achieving these amounts) have been proposed. In many cases, these lower limits are linked to a state-required bar on trading credits either in or out of the state, or in some cases in credit trading at all. (Some proposed state rules are, more simply, imposition of earlier target dates

[10] A. ter Schure, 2007; Critical Review: Methylmercury Exposure and Cardiovascular Effects, in L. Levin, *Mercury in the Environment: A Research Review*, EPRI Report 1012572; Final Report, March 2007; Electric Power Research Institute, Palo Alto.

for compliance, or acceptance of the EPA CAMR limits but barring of trading). EPRI has modeled the resulting emissions, using an economic costing model, as well as the resulting deposition patterns, and compared them individually and in combination to levels that would result if all states instead adopted the Federal CAMR rule (and, where applicable, CAIR leading to mercury reduction as a "co-benefit" of NOx and SO_2 control) and to a theoretical case where all U.S. utility mercury emissions are set to zero. The following paragraphs summarize the findings from those modeling studies of emissions scenarios.

EPRI modeling results found that, in most instances, step s by states to impose utility mercury limits lower than those of the U.S. EPA (CAIR, in the applicable states, plus CAMR, including trading of mercury emissions credits) tend to have little further impact on reducing deposition Indeed, the modeling found that barring of trading may result in slightly higher mercury deposition, in isolated instances, in "90% states" compared to what the EPA rules alone would provide. This is due to the generally earlier and more complete control of divalent mercury emissions by utilities under either Federal or state rules, The form of mercury remaining in utility emissions following this Phase I is mostly the less-easily captured elemental mercury. Elemental mercury typically travels thousands of miles before possibly deposi ting, and so tends to remain in the global pool instead. In isolated instances, states with utility mercury emissions containing high proportions of divalent mercury may have more notable deposition drops in some locations, though not overall. The impositi on of no-trading rules by some states removes economic incentives for utilities to control mercury beyond the Federal or state levels to generate trading credits. The result is some individual locations would experience slightly greater deposition following stricter and earlier state control than would occur under the Federal CAIR/CAMR rules. This is reflected in Figure 2, showing differences in deposition values in Pennsylvania and New Jersey under those states imposing a 90% cut with no trading, compared to the deposition that the EPA rules alone would bring.

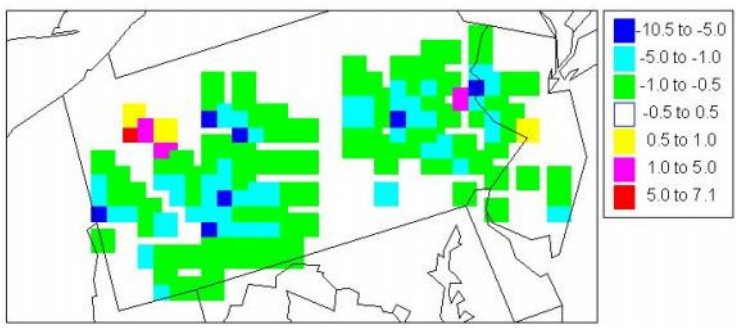

Figure 2
Differences in deposition, micrograms per square meter per year (($\mu g/m^2$-yr), Pennsylvania and New Jersey, for 90% utility controls (no trading) vs. full EPA CAMR compliance

Overall, EPRI (and other) researchers have found that, once utilities attain the EPA 70% national control goal, further controls on mercury have a declining "payback" in public health improvement. That is primarily because the form of mercury remaining in utility emissions nationally, once full compliance is reached with the EPA CAMR, will be the less -easily-deposited elemental mercury. Elemental mercury typically takes thousands of miles from its source point into the atmosphere for even a few percent of the amount emitted to deposit to ground level. Most of it enters the global atmospheric mercury pool, thoroughly mixed with the many non-U.S. emissions of mercury (U.S. utility emissions today are less than 2% of global anthropogenic emissions). Nonetheless, it is important to seek viable control measures for utility mercury, and EPRI has strived to do so for at least 20 years. Those efforts are now bearing fruit.

PERFORMANCE AND COST OF MERCURY CONTROLS – STATUS APRIL 2007

This portion of EPRI's testimony provides comments on questions about mercury (Hg) control that are commonly raised during discussions at the state level on adopting the Clean Air Mercury Rule (CAMR) versus a stricter standard. Usually, the control technology discussion revolves around two questions: (1) how effective are mercury controls, and (2) are they commercially ready. Underlying issues often are the ability of mercury controls to achieve 90% reductions across the board and the associated costs.[11] The responses to these questions, provided below, are based on data we have obtained since about 2001 in collaboration with many power companies and, most often, the U.S. Department of Energy - National Energy Technology Laboratory (DOE-NETL).

The fuel a power plant burns and its existing and planned air pollution controls determine (a) the amount of mercury that is captured as a co-benefit of mandated NOx and SO_2 controls (i.e., at very low incremental cost), and (b) the cost of mercury-specific control technologies (e.g., the need to add a baghouse as a secondary particulate control). The NOx and SO_2 controls may be in place due to earlier legislation and regulations or are being installed in response to the Clean Air Interstate Rule (CAIR). Therefore, the following discussion is organized by fuel.

Mercury Capture Performance

Bituminous coal-fueled power plants

Plants equipped with a selective catalytic reduction (SCR) system for NOx control, an electrostatic precipitator (ESP) for particulate control, and flue gas desulfurization (FGD) for SO_2 control have been shown to capture between approximately 70% and 90+% (only ~35% at one site) of the mercury in the coal, as received. This "co-benefit" for mercury capture from the installation of the other air pollution controls occurs because most of the mercury entering the FGD is in a soluble form (e.g., $HgCl_2$ or some other soluble oxidized species, often written generically as Hg^{+2}) due to the combined oxidizing effect of the SCR and the chlorine in the flue gas; elemental Hg is not captured by an FGD. However, it is difficult to predict (or understand) the reasons for the range of results. For example, one site has 95% Hg^{+2} at the FGD inlet and the FGD removes 95%. Theoretically, this should give a total mercury removal of ~90% (95% of 95%). However, due to re-emissions (conversion of the Hg captured by the scrubber back into elemental Hg, which is volatile and escapes from the FGD into the flue gas), the actual Hg removal is 86%. We are currently trying to understand why these co-benefits are so often < 90% and, then, will try to enhance or supplement these co-benefits so as to achieve the desired Hg reduction levels.

Routinely achieving 90+% Hg capture may be harder for plants equipped with a hot-side ESP (HESP)[12], as the test data all come from plants with cold-side ESPs (CESP), which treat flue

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[11] A plant would actually need to achieve 93-95% Hg capture routinely in order to assure compliance with a 90% limit.

[12] Cold-side ESPs are located following the air preheater, where the flue gas temperature is about 275ºF to 375ºF. At that temperature, the small amounts of unburned carbon in the fly ash have some affinity for mercury. Hot-

gas at a temperature where some Hg capture (typically 10 -30%) can occur on the fly ash; very little Hg is captured in the higher temperature ESP.

The data obtained by power companies in response to the US Environmental Protection Agency's (EPA) 1999 Information Collection Request (ICR) suggest that plants burning a low-sulfur eastern bituminous coal and equipped with a spray dryer and baghouse can achieve very high mercury removals. We have not collected any independent data on such units, so can provide no comments on the applicability of those results to other plants.

A still-to-be-resolved issue is mercury controls for smaller, older power plants that cannot justify the cost of SCR and FGD. The only tested Hg control for these plants is activated carbon injection. However, because the SO_3 present in the flue gas from such plants inhibits the capture of mercury by activated carbon, the amount of sorbent that would be needed to achieve 90% Hg capture would be very large (e.g., up to 20 lb/Macf[13]), would cost about $6.5M/yr for a 500 MW power plant, and would typically require a major upgrade of the particulate control system. One such upgrade could be EPRI's patented TOXECON™ process, which consists of adding a baghouse (also known as a fabric filter) behind the ESP and injecting the carbon between the ESP and baghouse. This approach has the added benefit of reducing sorbent usage significantly and maintaining the fly ash free of activated carbon, thereby enabling the plant to continue to sell it. While TOXECON may be technically feasible at plants that burn relatively low-sulfur coal (e.g., less than about 1.5% sulfur), it has not been demonstrated at plants fueled by medium- or high-sulfur coal. It is possible that the injection of calcium or sodium compounds to capture the SO_3 produced in these plants may prevent the harm it does to the bag material,[14] but tests of this approach are just now being conducted, and only at sites with ESPs and relatively low SO_3 concentrations.

Powder River Basin coal and Fort Union (North Dakota) lignite-fueled plants

The mercury capture behavior of PRB and Fort Union lignite tend to be similar, so the comments we provide here for the widely used PRB apply to both fuels.

The only approach for capturing high levels of mercury in PRB-fired units that has been tested extensively is sorbent injection. Three configurations have been tested – injection ahead of a cold-side ESP (CESP), TOXECON, and injection ahead of the last 1-2 electrical fields of a large CESP (TOXECON II™).

- *Injection ahead of a CESP.* In tests at several sites injecting ahead of the CESP, researchers have measured as much as 94% mercury removal over a thirty day period using brominated activated carbon. However, at other sites, the results have not been as high, at least not for injection rates in the 2-5 lb/Macf range. Sites that must inject SO_3 into the flue

side ESPs are located ahead of the air preheater at temperatures between 600ºF and 800ºF; at this temperature the unburned carbon captures essentially no mercury.

13 Activated carbon injection rates are normally reported as pounds of carbon injected for a given volume of flue gas. The volume is expressed as million actual cubic feet, or Macf. Research has shown that results from different tests can be compared rationally using this measure of carbon usage.

14 The harm is actually caused by the sulfuric acid that forms when the SO_3 and water in the flue gas react at temperatures often experienced in baghouses.

gas upstream of the CESP to achieve acceptable particulate collection will experience poorer activated carbon performance, for the reasons cited in the discussion on bituminous coals. EPRI and others are attempting to overcome this impact of SO_3 on Hg removal rate through such mechanisms as co-injection of the carbon with an alkali sorbent, but the results are not definitive, especially not at the 90+% removal level. The upper injection rate (5 lb/Macf) *may* be the maximum that can be injected without giving rise to particulate emission increases by an amount that triggers New Source Review (NSR); it is possible that NSR could be (a) avoided if the ESP has margin (i.e., is large enough and can be operated at a higher power level than normal), or (b) triggered by lower injection rates if the ESP is small and/or has no margin; the trigger increment is extremely small (e.g., an increase of ~0.001 lb/MBtu for a 500 MW plant). Still remaining to be determined is the potential for bromine emissions when bromine-impregnated activated carbon is used. Earlier tests by EPA at DTE Energy's St. Clair station indicated there were no measurable bromine emissions, but recent tests have found trace amounts in the flue gas – e.g., ~ 1 ppm, which is enough to produce > 10 tons/yr from a large boiler.

With most activated carbons, power plants that use them cannot sell their ash for use as cement replacement in the manufacture of concrete, the most common use of fly ash. [15] While one company offers a "concrete-friendly" brominated activated carbon, we do not know if it can produce >90% Hg capture at comparable injection rates at sites equipped with ESPs. Further, we are just obtaining some very preliminary indications that the bromine in the carbon impacts concrete strength. Further testing is needed to determine if this will be an issue. Other firms are developing non-carbon sorbents that may not hinder the use of ash in concrete, but they have not yet been demonstrated, and certainly not at the 90+% Hg capture level.

- *Injection ahead of a hot-side ESP (HESP).* This configuration has been tested at a few low-sulfur eastern bituminous sites using activated carbons specifically formulated for the higher temperatures in these ESPs. The results have been promising, but generally lower reductions than in CESPs. Tests are currently planned with a non-carbon sorbent called MinPlus that appears to be effective at very high temperatures (> 1500ºF). If the developer's results to date in privately-sponsored tests are duplicated in the DOE/EPRI-sponsored tests, this sorbent would provide a useful option for plants firing PRB, independent of the location of the ESP. Those tests will also need to determine if this material can be injected in the amounts needed to achieve ≥ 90% mercury capture without triggering the NSR increment for particulate.

- *TOXECON.* This is the technology being demonstrated at We Energies' Presque Isle power plant under a DOE Clean Coal Power Initiative. [16] In recognition of the risks of installing this new, capital-intensive technology, DOE is providing about half the funds for the project, the first installation designed from the start as a TOXECON application. Its benefits are (a) separation of ash and injected carbon, thereby allowing the plant to retain the sale of 95-99% of the ash, and (b) much lower sorbent consumption. We understand

[15] Carbon interferes with the ability to embed air bubbles in the concrete that allow it to expand and contract without cracking when the ambient temperature changes. The mercury, itself, is not an issue as it is immobilized in the concrete.

[16] Note: TOXECON may not be applicable to plants burning a medium-to-high sulfur coal due to rapid bag deterioration by the sulfuric acid in the flue gas.

from the We Energies Project Manager that the technology is now achieving 90% Hg capture and the team has resolved the hopper fires it encountered during the first few months of operation, but is still working to eliminate the fugitive dust from hopper unloading. We note that both of these issues were unexpected. We also understand that the Hg capture level for a given activated carbon injection rate is very temperature -sensitive, another unexpected finding, and one not seen elsewhere.

- *TOXECON II.* This EPRI-patented variation of TOXECON may be applicable to power plants with large CESPS. It retains the salability of 90-95% of the ash by injecting the carbon ahead of the last 1-2 electrical fields of the ESP, thereby avoiding the large capital cost of a TOXECON baghouse. This approach recognizes that 90-95% of the ash is collected ahead of these fields. The challenge is to inject enough activated carbon to capture substantial amounts of mercury without increasing particulate emissions by more than the increment that triggers New Source Review (NSR). Tests conducted at Entergy's Independence station in Texas, which has a very large ESP (8 fields, specific collecting area [SCA] = 540 ft^2/kacfm), have shown short-term Hg removals of 60-70% at injection rates of 2 lb/Macf and 80-90% at 6 lb/Macf, using brominated activated carbon. Particulate emission tests have not yet been conducted and analyzed. Give the low NSR increment for particulate matter, it is likely that carbon injection at the rates needed for 90+% Hg capture at most power plants will trigger NSR; this would lead to a requirement to upgrade the ESP, thereby decreasing the cost advantage of TOXECON II.

- *Other options for PRB-fired power plants*. All but the last of these options will be capital intensive. They include:

  - <u>Addition of an SO_2 control and mercury-specific catalyst within the ESP</u>. This approach has shown moderate success in some applications and less success in others. Plans are currently underway to demonstrate it at the 200 MW scale on Lower Colorado River Authority's Fayette station. To be cost competitive with sorbent injection (even if ash sales are lost), the catalysts will have to last 1 -2 years without needing removal and replacement or external regeneration. Further, the catalysts and configurations tested so far have started by oxidizing ~90% of the elemental mercury and have declined in performance over 6 months. Since the FGD does not capture 100% of the oxidized mercury it sees, the overall performance is unlikely to be 90% with any great frequency and certainly not as a long-term average.

  - <u>Addition of a spray dryer for SO_2 control followed by a baghouse</u>, and use brominated activated carbon. Testing at plants already equipped with these systems showed mercury capture rates > 90% over a 30-day period. We have no data on plants with a spray dryer retrofit ahead of the existing ESP (i.e., without a baghouse), but expect the mercury removals to be much less for any given carbon injection rate.

  - <u>Addition of an SCR and FGD</u> may be effective for mercury control if new catalysts provide the high mercury oxidation rates in PRB flue gas that one supplier has reported. This is a potentially emerging approach that has just begun to be tested; therefore, it is several years away from being proven.

– Add a halogen to the coal (e.g., a bromine compound) to promote the formation of the soluble oxidized mercury species in the air pollution control zone of the boiler. This emerging concept, still under investigation, would also require an SO_2 control but no baghouse and, possibly, no SCR (for achieving high mercury removals by the FGD).

– Pre-treatment of the PRB to remove mercury. One example is the K-Direct™ process being developed by Evergreen Coal. Through the application of pressure and temperature, they drive off much of the water in the coal and, reportedly, with it up to 70% of the mercury. This approach is still in the development/perfection stage, and it would not achieve 90% mercury reduction (coal-to-stack); that would require a post-combustion control that provided 70% capture of the remaining mercury.

The first four approaches would be economically competitive with other technologies only if the plant had to install the NOx and/or SO_2 controls to meet stricter emission limits than achievable by their current configuration and fuel.

Costs of Mercury Control

EPRI recently updated its cost estimates for mercury capture (see report # 1012672, cited earlier) and predicted the following costs for the above-mentioned mercury controls for plants burning PRB or Fort Union lignite. The cost figures are for 90% control.

Mercury Control	**Capital ($/kW)***	**Cost of electricity (¢/kWh)**	**Comments**
Activated carbon injection ahead of ESP	4	0.15	Assuming ash not currently sold
		0.36	Assuming ash currently sold and cannot with sorbent injection**
TOXECON	50-250	0.52	Capital costs based on recent bids; range due to wide differences in site configurations/space
TOXECON II	7-20	0.24	Upper capital cost assumes 1 field added to ESP. Technology may be limited to 70% mercury capture.

* For reference, $1/kW equates to $300,000 for a 300 MW plant. Hence the TOXECON capital costs range from $15-75M for this size unit. New plants are estimated to cost around $2,500/kW, so the TOXECON capital costs are equivalent to 2-10% the cost of a new plant.

** Assumes $60/ton ash cost combined revenue loss in ash sales + disposal costs.

To put the capital-intensive technologies for PRB-fueled plants in perspective, typical retrofit capital cost ranges are given below.

Technology	Capital ($/kW)	Impact on cost of electricity (¢/kWh)
Spray dryer (using existing ESP)	300–400	0.7–1.0
Spray dryer/baghouse	400–550	1.0–1.4
SCR	200–300	0.5–0.7
FGD	350–500	0.9–1.2
Oxidation catalyst	~25	<0.1

Commercial Readiness

For new technology, the question of when it is "commercially ready" is largely a business assessment by the purchaser on the strength and remedies of the supplier's guarantee (relative to the financial impact on the power plant of not meeting the required emission limit or percent removal requirement). Because this is not a technical question, EPRI does not procure equipment, and we are not privy to contracts between suppliers and power companies, we are not in a position to provide substantive comments on the commercial readiness of the two technologies that have been sold with guarantees – injection ahead of an ESP and TOXECON (according to press releases and Institute of Clean Air Companies (ICAC) information sheets). We can say that EPRI's TOXECON II process is still in the development stage, as we continue to work to improve the sorbent injection system to provide >70% Hg removal. In addition, we have not yet demonstrated that the injection this far back in the ESP does not increase particulate emissions enough to trigger NSR or that the separation of the ash catch from the last fields does not reduce the fines content of the ash sent to the concrete plant to a level that's unacceptably low for them.

Discussions in the states often leave the impression that they are talking about the commercial readiness of mercury controls that could be used to achieve a 90% reduction in all plants, often without saying so explicitly. The press releases and ICAC information did not state whether all the systems that have been sold or bid for injection ahead of an ESP provide the following set of guarantees: 90% Hg removal, no increase in particulate emissions large enough to trigger NSR, and, for cases where the supplier is providing a "concrete friendly" sorbent, that the ash quality will meet all the concrete manufacturers' quality requirements. For TOXECON, ash quality would not be a guarantee issue, but pressure drop across the baghouse and lifetime of the bags would be. These expectations are akin to the normal practice when procuring an FGD of requiring the supplier to guarantee not only SO_2 removals (or emission levels), but also pressure drop, reagent use rate, particulate/droplet emissions, and gypsum quality, as well as knowing that every supplier can provide a system that achieves a 98% SO_2 removal or even higher.